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Size Distribution of Pink Salmon

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SIZE DISTRIBUTION OF PINK SALMON

by

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Studies in oceanography, mainly in support of fisheries investigations of the Fisheries Research Board of Canada at Nanaimo, led to particular perceptions of the relationship between the physical character of the sub-arctic North Pacific Ocean and the ocean distribution of Pacific salmon. Migrations of young and adult to and from the ocean forage area take place during the same period each year and over relatively long distances close in to the coast, so that interactions, with consequences in distributions, were indicated, especially during the big sockeye years on the Fraser River. As I describe here, the distribution of size in pink salmon is another consequence.

ABSTRACT

Barber, F. G. 1980. Size distribution of pink salmon. Can. MS Rep. Fish. Aquat. Sci. 1564: 20 p.

Observed variations in average size of seine-caught adult pink salmon in an even-year are shown to be inversely related to the number of pink and sockeye adults returning to the Fraser the previous year.

Key words: pink salmon; average size; predation

RÉSUMÉ

Barber, F. G. 1980. Size distribution of pink salmon. Can. MS Rep. Fish. Aquat. Sci. 1564: 20 p.

Les variations observées au niveau de la taille moyenne du saumon rose adulte capturé à la seine au cours d'une année paire semblent inversement proportionnelles au nombre de saumons roses et rouges adultes qui ont remonté le Fraser l'année précédente.

Mots clés: saumon rose; taille moyen; prédation

Characteristic of pink salmon populations are rather drastic variations in abundance (e.g. Neave 1962; Ricker 1962; Skud 1973). It was an early impression that the variations would eventually be shown to have an association with parameters like escapement, fry survival, and marine survival, but as yet a simple relationship has not been achieved (Ricker 1972; Peterman 1978). Here I present additional support for the speculation that year-class interaction through cannibalism has significance in distributions of pink salmon (Barber 1979a) and demonstrate in data an inverse relation between mean size (weight) of even-year fish caught in ten statistical areas and the number of odd-year adult returns to the Fraser River. The relation supports the assumption of a size-selective predation and the idea that early freedom from predation of Fraser fish makes their statistics potentially more useful indices of ocean effects. I can only suggest one such effect and emphasize that the mechanism proposed for the influence on abundance, i.e. predation by fur seals, is speculation. An ocean influence on abundance (achieved through a non-size-selective predation), and a predation by mammals during the period salmon are dispersed, rather than schooled, appeared appropriate. The distribution in time and space of seals, the predators, is variable, so that the number of salmon consumed in an area is a variable (Peterman and Gatto 1978, p. 800) and a variation in adult returns to particular areas results (annually over the ocean the total number of prey may be a constant).

Ricker, Bilton, and Aro (1978), hereafter RBA, applied simple regression to catch statistics and apportioned responsibility for the decline in size of pink salmon to changes in ocean and in methods of exploitation, i.e. gillnetting and trolling. They speculated that gillnetting, including changes in its application (artificial fibres and mesh size), was likely of first importance. I suggest that trolling may be of greater significance than gillnetting and that predation may be the origin for other aspects of the distribution of size of pink salmon. Quite unexpected was the result that sockeye, as well as pink, adults appear to participate in this predation on pink fry and so cause the variations in size. According to Neave (1966, p. 73) these variations "are commonly in the same direction throughout the length of the British Columbia coast" (see also Skud 1958, p. 176); however, a clear relation has not yet been found between ocean conditions and fluctuations in either abundance or average weight (note 1). The relationship I show is clear; it is described initially in the context of pink salmon and then in a relation including sockeye. Finally, I note in the size distribution of sockeye similarities with that of pink salmon and from the estimated returns to the Fraser River in 1979 I forecast the weight of seine-caught pink salmon in 1980.

INTERACTION BETWEEN YEAR CLASSES

I begin with an example of the inverse relation (Fig. 1) found between the number of returning pink adult in an odd-year (e.g. Anon. 1978) and the mean weight the following even-year (RBA); a relation that provides support for the approach taken, i.e. that cannibalism occurs and is size-selective. The figure indicates that the impact of odd-year Fraser fish on fish to other areas is such that the greater the abundance of Fraser fish the smaller

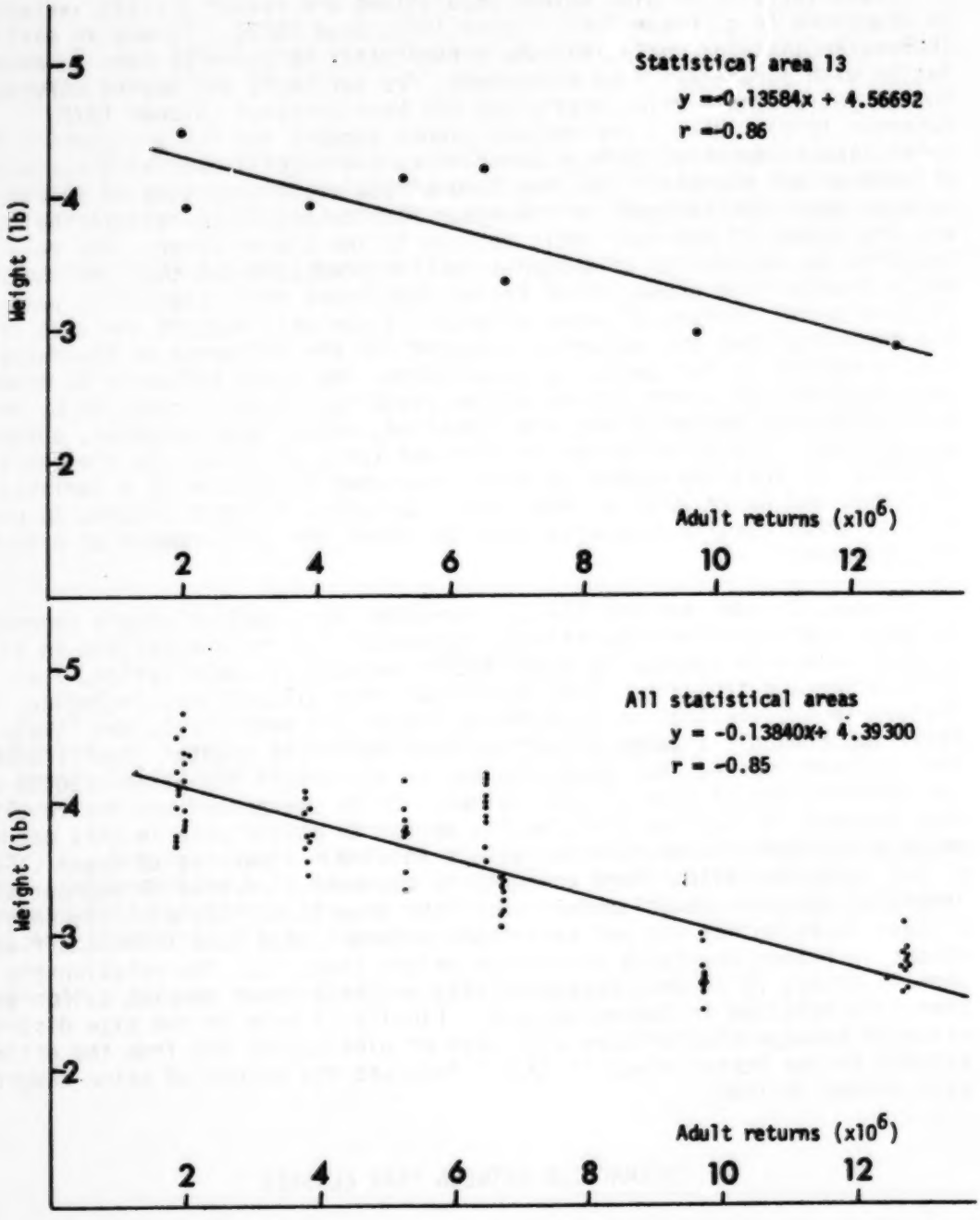

Fig. 1. Adult pink salmon returns in odd years (1959-1973) to the Fraser River and mean whole weight of seine fish the following year (from Table 1). (a) Returns and mean weight in statistical area 13. (b) Returns and mean weight in each statistical area of the table.

the size of the following even-year adult. For the relation to be apparent it is necessary to have an adequate number of sea-going fry "meeting" an adequately large number of returning adults. Fraser River pink in the odd-year represent a large portion of the total number returning to west coast streams, so that should interaction between year-classes be significant, a relation with numbers of Fraser fish might be clearest. As the river is one of extreme disparity (Neave 1952) the interaction must be shown to be with fish to other streams, and, usefully, as there are no adults in the even-year the catch in each statistical area, i.e. the mean whole weight, is not influenced by Fraser fish (RBA, p. 3).

A better "fit" would result (Fig. 1) were the value for the returns in 1959 a million or two less than the six and a half million estimated. That the value could be error seems likely as the determination of the catch of Fraser fish in other areas may have been complicated in 1959 by overfishing (Anon. 1960, p. 23). Interestingly, a large catch in Convention Waters occurred in 1947 (e.g. Anon. 1978, p. 49) and although I was not able to find general comment about the size of fish in 1948, seine-caught weights as given by Godfrey (1959, p. 330) indicated relatively small fish that year. Godfrey's data also show that fish were lighter in 1946 than in 1948, while data on trap-caught fish at Sooke (Neave 1953, p. 463) suggest a larger return of adults to the Fraser in 1945 than in 1947, as do data on the estimated catches in the central region of British Columbia for 1945 and 1947 (Neave 1953, p. 460). With Godfrey's data, adjusted for the recent decline in size (RBA) and with the relation of Fig. 1, I suggest an adult return to the Fraser in excess of 12 million fish in 1945 and about 8 million in 1947.

But what of the influence of returning even-year adults? Recalling that the mean whole weight in many statistical areas is influenced by Fraser fish (RBA and above) and as there is no return in even years to the Fraser, an interaction might best be expressed in adult returns in even years to other streams against the mean weight of Fraser fish. A difficulty is that as there is no return in the even year to the Fraser the sea-going fry that year (odd-brood year) do not feel the impact of returning adults until much further out of the system (so they are larger than fry of the even-brood year). Thus cannibalism could be of less significance to Fraser fish. Certainly I was not able to show a relation between returns (catch plus escapement) in even years (Aro et al. 1977) and weight of odd-year fish to the Fraser, or other statistical area, except that the large fish of 1933 and 1961 followed the crash in population in each of 1932 and 1960 (see later). There is then the possibility that Fraser fish provide a better expression of ocean effects than any other, a possibility supported by the analyses of RBA wherein, "all the salinity regressions are positive, but that for the Fraser is the only one that approaches significance."

SELECTIVITY

That trolling can be selective (Milne 1955; Pitre 1970) and might lead to changes in salmon behaviour (reaction to lures, depth distribution, and increased wariness) was a frequent topic in discussions between fishermen (trollers) from my earliest experience. However, there is nothing in the

literature which would point to such an influence (Miller 1957), and while RBA suggest that the distribution of size of pink salmon (Fig. 2) may reflect a genetic influence of size selection in the gillnet and troll fisheries, I could not locate a recent study of size-selection in trolling. On the other hand gillnets can be strongly size-selective (e.g. Hamley 1975). But most escapement in gillnetting occurs during shutdowns; of the Skeena River gillnet fishery for pinks Todd and Larkin (1971, p. 841) remarked, "it seems reasonable to conclude that selective effects are not a major factor in the population biology."

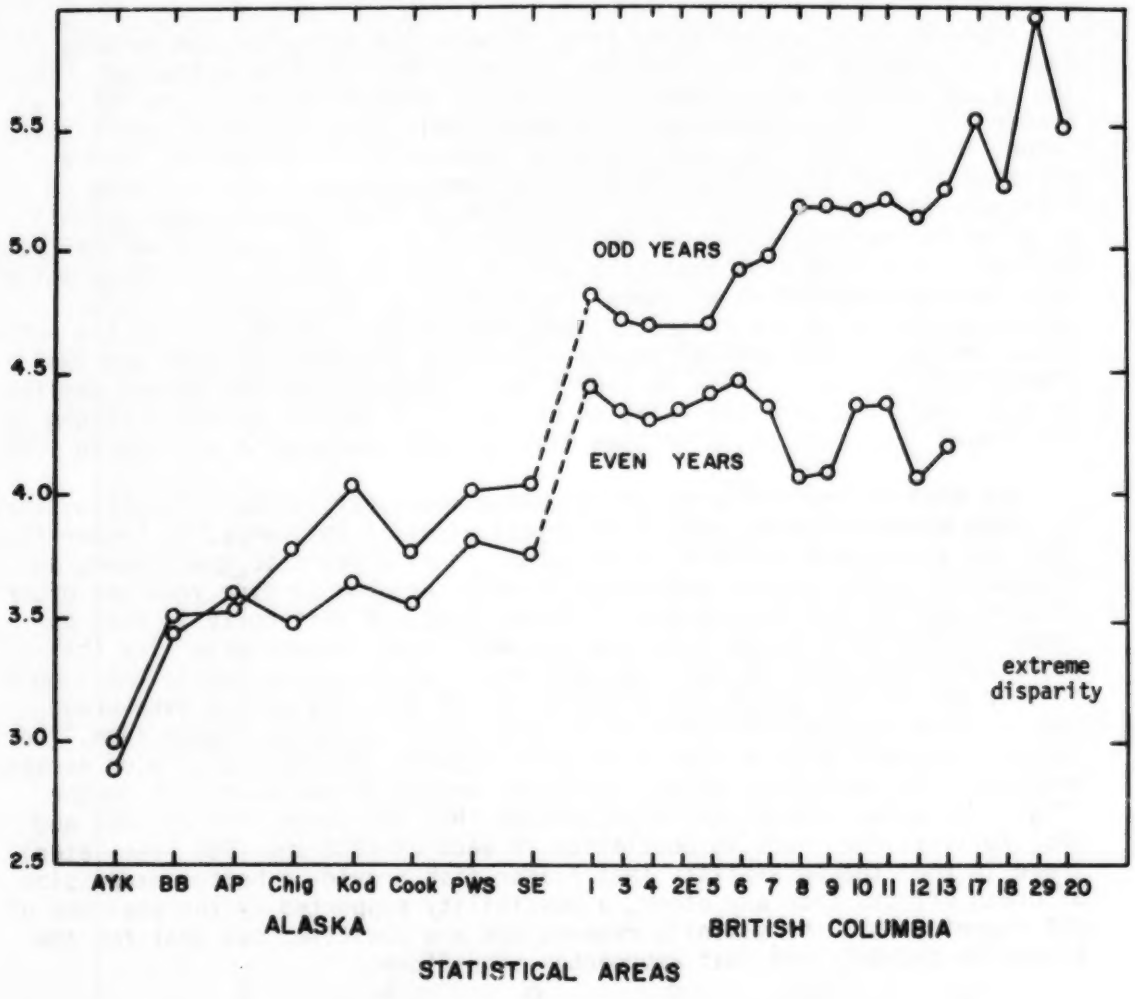

Fig. 2. A re-presentation of figure 3 of RBA to which the phrase "extreme disparity" has been added at about the area of the Strait of Georgia - Puget Sound system. The caption read in part: "Trends in the mean weight in pounds of pink salmon catches, arranged geographically from north and west to south and east... Figures for Alaska are for 1960-74, and include catches by all gears; those for British Columbia are for 1951-75, and represent gillnet catches only."

If the decline in size is real and if the seine is nonselective (Verhoeven and Davidoff 1962, p. 119) the decline should be greater in seine-caught fish, and this was observed (RBA, p. 10). RBA also noted (p. 11) that the existence of the difference ruled out environmental influence in the decline in size. Following this reasoning it seemed appropriate to pursue the effect of the rather intense management carried out without complete understanding, i.e. carried out by managers whose considerations were in part speculative (Larkin 1972, 1977), and in particular to determine whether there have been practises so consistent in time that their influence on heredity could be recognised (note 2). One such is the freedom from periods of closure each season "enjoyed" by the troll fishery. As there are no shutdowns the consideration above of Todd and Larkin (1971) cannot apply. Shutdowns ensure complete size representation in the escapement, whereas without shutdowns of a size-selective fishery certain sizes may be removed altogether. As a working hypothesis I assumed that trolling removed the largest fish in each run and so removed this characteristic from the gene pool in cumulative fashion (note 3).

SIZE-SELECTIVE CANNIBALISM

Trolling for pinks is fairly recent, as is the decline in size (note 4). This correlation and that of largest size with an area of extreme disparity (Fig. 2) were compelling, and with the association of maximum mean size and the southern edge of the distribution of pink salmon strongly suggested that the gillnet fishery was not a factor in the distribution of size, but that a size-selective cannibalism was.

Ivlev (1961) showed size-selective predation could produce shifts in median size in a laboratory population and more recently Parker (1971) suggested a mechanism of selection in predation of coho smolts on young pinks that could reduce predation on a population of chums. In the latter experiment the selection was for the smaller individual, whereas Ivlev's model is based on selection for larger size; here I follow Ivlev and assume a predation in which the selection is for the larger young (note 5).

Other characteristics of cannibalism may prove significant. First, as the predation (cannibalism) is nonobligatory the resulting mortality is depensatory (Parker 1971, p. 1510; Neave 1953, p. 465), i.e. as the predator population is not numerically related to the number of prey, cannibalism has the potential of removing the same quantity of prey at each occasion of habitat overlap and so eventually causing extreme disparity. Second, extreme disparity could also result if, in a particular area, on-year adults prey on the few young of adults (strays?) to barren streams there in the off years, i.e. if refugia do not exist for any offspring of the off-year class, they may be eliminated (Peterman and Gatto 1978). A refugium important to some populations is the growth of the young to a size larger than some limiting size considered accessible as a prey item by the adult (e.g. Ivlev 1961 and note 6). In encounters of adult and young which involve cannibalism, I assume that all young are smaller than limiting size, so all are potential prey, and that the handling time (Ware 1972) is a constant. Thus the most profitable fry in terms of net food value are the largest fry (e.g. Krebs

1978).

Should the adult predator select for a particular characteristic, cannibalism could influence the distribution of the characteristic in the young and hence in the eventual adult population. In a review Fox (1975) noted that "the role of cannibalism in the dynamics of natural populations has been largely neglected" and Chevalier (1973, p. 739) remarked, "Cannibalism is a potential regulatory mechanism in fish populations..., but its importance in natural populations seldom has been demonstrated." Aspects of this potential with regard to pink salmon were described (Ricker 1962), i.e. the potential influence on abundance, and cannibalism was suggested as the cause of extreme disparity; it reflects a density-dependant relationship at a particular time in the life of the young and the adult brought about by physical factors (Barber 1979a). Although "extreme disparity, while it occurs in widely separated areas, is local and infrequent" (Neave 1952, p. 63) it has maintained over the history of the modern fishery certain well-known features; particular examples are the off years in the Fraser River - Puget Sound system and in the northern Queen Charlotte Islands.

AN OCEAN EFFECT

On two occasions, in 1932 (Howe 1933) and 1960 (Wood 1977), the large even-year run to the Queen Charlotte Islands did not materialize, i.e. unusual disparity seems to have occurred in on-year runs (note 7). There is evidence that the crash of 1932 (Neave 1966) was the result of poor escapement in 1930, a year the pack exceeded 1 100 000 cases (Neave 1962, p. 4), but that of 1960 seems not to be related to escapement, at least not to the northern Queen Charlotte Islands in 1958 (Brown and Musgrave 1979). That the small returns each year (1932 and 1960) may reflect ocean effects seemed possible and I recalled the anomalous conditions of the late 1950s and the consideration that the migration route of salmon was altered (note 8). But perhaps the unusual conditions led to an unusual distribution of predator, e.g. the fur seal, and to an unusually high level of predation in a particular region. The impact of the fur seal is likely heaviest at the time the maturing pink salmon are preparing to leave the ocean along the west coast, i.e. in June, and when the fur seal generally are abundant there (Kenyon and Wilke 1953). A return to typical, or relatively low levels of predation, would depend on the extent a relaxation in the ocean condition occurred. There is however no evidence in data to support the motion; indeed the occurrence of near-average mean weights in all statistical areas in 1960 (RBA their Table 4) argues against predation, at least against a size-selective predation. But perhaps ocean predation is not size-selective. Consider that while in the ocean the fish are so separated by their response to the content of Langmuir circulations (Barber 1979b) that comparison for size by a predator is not possible. Consider too that predation on salmon is generally heavy and that the distribution of this predation has particular pattern, i.e. that both predator and prey have characteristic distributions in time and space, but one that can be varied by ocean conditions. Variations in abundance then could occur without reflection in mean weight. So I was led to the possibility that predation by fur seals was a factor in

levels of abundance of salmon.

Spalding (1964) concluded that sea lions and harbour seals were not important predators on salmon in British Columbia waters, but emphasized that knowledge concerning the influence of migrating fur seals in both inshore and offshore waters was "far from complete," while Ricker (1968) was inclined to believe that seal predation was not important. The subject was touched on in a workshop (Peterman 1975; 1978, p. 1447) and modelled by Laevastu and Favorite (1977) relative to the fishery in eastern Bering Sea. Their computations showed that "50,000 tons of salmon are consumed by pinnipeds" (p. 39), which suggested an influence equivalent to that of the commercial fishery. As in Lower Seal Lake, this predation could select "against large size" and so have rather specific influences on populations (Power and Gregoire 1978), but as suggested this is not likely in the North Pacific as the fish are dispersed.

The anomalous average weight in each of 1933, 1946, 1961, 1968, and 1972 was initially accepted as due to natural influences (note 9), perhaps an ocean effect (Peterman 1975), and I considered several ocean indices. In the development of such potential relationships I noted that two years of larger than usual fish, 1933 (Hoar 1951, e.g. fig. 7) and 1961 (RBA), followed the crash years of 1932 and 1960, and the years of relatively small fish, 1946, 1968, and 1972 (Bilton 1973), followed years in which an unusually large number occurred in parts of the coast. According to Neave (1953, p. 460) the "total run" for 1945 to the central region of the (B.C.) coast was well above average and the Commission report for 1971 indicated above-average runs to the Fraser in 1967 and 1971 (Anon. 1972, p. 26). This was the evidence for interaction between the year-classes noted at the outset, an interaction that required the mechanism I perceive as the cause of extreme disparity, i.e. cannibalism, and a variable oceanic predation that caused variations in abundance of returning adults.

The scenario thus developed comprises a cannibalism of adult on young in which the selection is for the larger young and a variation in the intensity of this selection (predation) due to a variation in number of adults returning to a particular area of the coast in a particular year. As the adults returning to the northern Queen Charlotte Islands in 1932 and 1960 were much smaller in number than usual, cannibalism of adult on young was much smaller than usual over that part of the area where habitat overlap generally occurred between the particular adults and sea-going young. I visualize an area positioned across the migration route of the young at about the latitude of Dixon Entrance and extending seaward from the inshore region well into the ocean. Here cannibalism was less and, because of the bias in predation to larger size, a shift toward larger median size occurred in each run as it moved through the area. The shift would persist in the run of young so long as the subsequent predation, i.e. predation downstream of the area, remained at normal intensity. In similar fashion the above average returns of 1945, 1967, and 1971 provided areas in which predation was greater than usual and so a shift toward smaller median size occurred in each run of fry as it moved through the area. Hence the smaller fish in 1946, 1968, and 1972.

In explanation of the decline in size RBA suggested a genetic influence arising from changes in the fishery beginning in the early 1950s. They

showed that on the average, fish of odd-numbered years were larger than those of even-numbered, particularly in British Columbia, and that the difference in weight increased from north to south (Fig. 2). Not only does the difference increase from north to south, but also as earlier remarked, at the southern limit of pink populations the odd-year fish are largest where the even-year fish do not exist; i.e. in an area of extreme disparity and at the edge of the population the odd-year fish are heaviest. Consider the young of the odd-year class of the Fraser River: in their seaward movement through the Strait of Georgia system they are free of cannibalism and as they move into the ocean they do not feel the impact of a large population of adult pink salmon moving to more southerly spawning areas. They are freer from predation by adults than are all other populations of British Columbia, including the even-year fish to the northern Queen Charlotte Islands (another area of extreme disparity). On the other hand young of the even-year class, particularly those from north Strait of Georgia to Queen Charlotte Sound, undergo the predation of adults returning to the Fraser, and just as the odd-year fish increase in weight toward the area of least cannibalism, the even-year fish decline (RBA, p. 3) toward the area of greatest cannibalism. This difference in abundance at the edge of major populations is perceived as the cause of the weight difference between individuals of the odd and even years. Thus, the difference in size and the north-south gradients strongly reflect the distribution of extreme disparity and likely existed prior to the fishery.

DISCUSSION

My earlier speculations concerning the role of physical distributions and processes in the ocean in the life of Pacific salmon seemed to comprise reasonably testable hypotheses. The influence of ocean predation on abundance and hence on the intensity of cannibalism seems also to be testable; however, the consideration of trolling is somewhat contrived and may rest on an influence of management not separable from other aspects of management, at least in North American data. But do data on stocks in Asia, where trolling is not significant, exhibit a decline in mean weight?

Trolling is under management, so that whatever could be proven could become the basis for change in management. Cannibalism is not yet under management, but neither is it proven. Nevertheless, the development here provides strong support for the existence of cannibalism and for selection by size, so that further consideration of the role of cannibalism may be acceptable. Given that the Pacific salmon occurred first as one of either an odd-or even-year pink (Barber 1978), the distribution of adult size in the year-class would not have exhibited the north-south gradient (Fig. 2). Cannibalism could not have been characteristic (note 10). That cannibalism occurred with the development of the other year-class and of such intensity as to cause extreme disparity in some areas strongly suggests an affinity for a particular aspect of habitat, perhaps determined by tidal motions and schooling (Barber 1979a and note 11). Thus a behaviour, schooling, adaptive in a species with but one year-class became maladaptive with the development of the other year-class. As the cannibalism is apparently nonobligatory and as the adult is not a near relative of the prey, it cannot

be considered altruism on the part of young to be preyed on by the adult. No, the existence of cannibalism in the species developed in the absence of the possibility of cannibalism, i.e. in the absence of the other year-class. Presumably, the prey of the adult pink of the only year-class were young of other predators in the system, sea-run trout perhaps, which it was adaptively useful to prey upon. Thus cannibalism as a maladaption may be the result of "inappropriate behavioural cues" due to mistaken identity (Coyne and Sohn 1977), as young trout resemble salmon fry (Phillips 1977).

It follows that adult pink salmon could prey on all salmon fry and that adult salmon could prey on salmon fry generally, presumably in a size-selective predation. Consider again the sea-going pink fry along the British Columbia coast in the odd-year: in addition to the generally large number of pinks returning to the Fraser area in those years the fry would "face" the returning sockeye adult (but not now those of the big four-year cycle), as well as adult salmon returning all along the coast. But the Fraser (and Puget Sound) is at the southern edge of both sockeye and pink populations, so that Fraser adults could have the greatest impact in a given year. This is supported in the regression line of mean weight of seine-caught pink on the estimated number of pink and sockeye returns the previous year (Fig. 3) where the relation with pinks caught even in the eastern Queen Charlottes (area 2E) has significance.

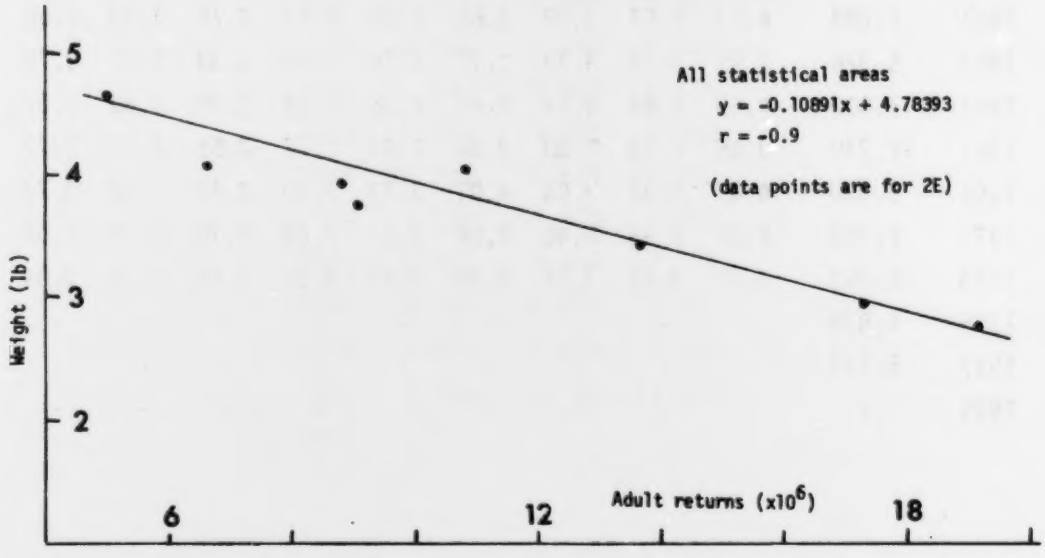

Fig. 3. The sum of pink and sockeye adult returns in odd years (1959-1973) to the Fraser River (from Table 2) and mean whole weight of seine-caught pink salmon the following year in ten statistical areas (from Table 1). Data points are for one of the statistical areas, i.e. for statistical area 2E.

Table 1. Number of adult pink salmon in odd years (1959-73) to the Fraser River as estimated by the Salmon Commission (Anon. 1978, p. 20) from catch and escapement data and the mean whole weight of seine caught pinks the following even-year in 10 statistical areas (from RBA).

Year of Return	Number ($X10^6$)	STATISTICAL AREA 1	2E	3	4	5	6	7	8	12	13
1957	-	5.49	4.84	5.24	4.85	4.98	4.90	4.44	4.46	4.45	4.44
1959	6.459	4.20	4.03	3.66	3.53	3.87	4.16	3.83	3.95	3.89	4.18
1961	1.884	4.13	4.07	3.99	3.68	4.09	4.23	3.75	3.73	4.06	4.49
1963	5.326	3.95	3.75	3.73	3.77	3.76	3.85	3.33	3.47	3.79	4.14
1965	2.000	4.55	4.64	4.18	4.30	4.35	4.34	3.83	3.89	3.82	3.94
1967	12.740	3.05	2.78	2.80	2.80	2.83	2.77	2.55	2.53	2.72	2.87
1969	3.830	4.07	3.92	3.64	4.01	3.73	3.70	3.46	3.52	3.73	3.94
1971	9.707	2.56	2.95	2.46	2.56	2.61	2.66	2.70	2.76	2.68	2.99
1973	6.753	3.46	3.42	3.14	3.34	3.42	3.27	3.18	3.15	3.04	3.37
1975	4.879	-	-	-	-	-	-	-	-	-	-
1977	8.173	-	-	-	-	-	-	-	-	-	-
1979	-	-	-	-	-	-	-	-	-	-	-

Table 2. Sum of adult pink and sockeye returns in odd years (1959-77) to the Fraser River as derived from annual reports of the Salmon Commission.

Year of Return	Number ($x10^6$)		
	pink	sockeye	sum
1959	6.459	4.405	10.864
1961	1.884	4.699	6.583
1963	5.326	3.800	9.126
1965	2.000	3.000	5.000
1967	12.740	6.500	19.240
1969	3.830	4.978	8.808
1971	9.707	7.604	17.311
1973	6.753	6.914	13.667
1975	4.879	3.678	8.557
1977	8.173	5.781	13.954
1979	-	-	-

Quite clearly the relationship suggested (Fig. 3) needs to be looked for in other data, but I have not found tabulations of statistics similar to those of RBA or the Salmon Commission. Data on mean weight likely could be derived from catch statistics, but the estimation of number of adult returns, catch plus escapement, to a particular river seems quite subjective, and certainly beyond me. But with the later estimate, a forecast of mean weight of seine fish to be caught the following year becomes possible. For example, the Salmon Commission anticipated a return of 18.8 million pink and sockeye in 1979 (Roos 1979) which with the aid of my relationship (Fig. 3) suggests small adult pink salmon in the 1980 seine fishery (note 12).

More important perhaps is the need to be certain about the occurrence of species and year-class interaction through predation. I suggested that cycle dominance in sockeye of the Fraser was the result of a mechanism similar to that which causes extreme disparity in pink salmon (Barber 1979a, b), and here size differences in pink salmon are seen to result from size-selective predation with largest fish occurring at the edge of major populations where predation is least. Data on weight of sockeye suggest other similarities with pink salmon, e.g. data on 4_2 sockeye from major producing areas of British Columbia (Killick and Clemens 1963, p. 97) indicate that the average weight for Fraser fish, i.e. for sockeye at the southern edge of their populations, is also the largest. As well, Killick and Clemens (1963, p. 110) remarked on a yearly alteration with larger fish in the even-years, which they attributed to a genetic influence; I note the largest average size occurs in the present dominant year-class (p. 110, item 18 of their Summary).

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NOTES

1) Wickett (1973, p. 2) suggested the decline in average weight of coho was not due to a size-selective predation but to a decline in amount of food.

2) Another management practise concerns escapement, wherein the regulations could favour a particular portion of a run. For example, at Sashin Creek the early fry are larger and have greater survival (Skud 1958) and would be favoured by later rather than earlier openings of the fishery. But some fisheries have been regulated by the date of closure so as to favour late runs and, according to Vaughan (1947), to lead to a progressive delay in the timing of the run. In others the early and late fish are not as heavily fished as those during the peak, which in time displaced the peak, while an attempt to stabilize the annual number of young removed a natural control of predators (Rounsefell 1958).

3) Corrective measures might include mandatory shutdowns, which might also assist catch division between the troll fishery and the "inside net fishery" (Anon. 1978, p. 4; see also Roos 1979).

4) Trends in size have been suggested (e.g. Skud 1973, p. 107), but RBA concluded that "the sustained decline in size of British Columbia pink salmon is a recent phenomenon..."

5) A reviewer of a draft questioned the assumption so that I was led to determine whether in literature contrary information existed in the circumstance that all the prey were less than limiting size for the piscivorous fish; non was found even though Nilsson (1978, p. 303) remarked that "during the last decade size-based predation has become more and more

prominent in the research of both zooplankton specialists and fishery biologists." This is true of course in the context of predation on zooplankton for which there is a considerable literature; an example is that of Eggers (1978) who remarked of juvenile sockeye in a lake that, "the largest zooplankton...were selected for when present." (Why not laboratory experiment (Ivlev 1961; Parker 1971) comprising adult and young pinks?).

6) Forney (1976) showed that cannibalism can be an important factor in recruitment to walleye populations in Oneida Lake. Here the "duration of cannibalism was determined by the growth rate of young walleyes" relative to the size of adult, i.e. as the size of prey increased (to about 175 mm in length) the predation by adults (usually less than 400 mm long) decreased sharply. Milne (1955) noted that herring eaten by spring salmon were smaller than 70% of those sampled in an adjacent, and presumably non-selective, fishery and suggested the limitation was "probably size of mouth" of the spring; the herring ranged from 150 to 190 mm in length and the large spring were about 660 mm. In this it seems appropriate to assume (after Ware 1972, p. 1199) that, like trout, pink salmon are "obligate visual predators", so that for prey, being larger means being in higher risk of discovery (Hestor 1968). Other limitations to visual detection then need to be examined, particularly as the visibility in surface waters of some inlets can vary markedly (Pickard 1961). In this regard the direct association of glacial runoff with fry movement out of freshwater may be significant; turbidity may be a refugium during a critical period for some fry. Why for example is there a run in the off-year to the Yakoun River (Walker 1970; Brown and Musgrave 1979)? As the Yakoun rises in boggy land it is dark, tea brown in colour (Walker 1970; Brown and Musgrave 1979) which may limit the visibility of young to a predator in the area of influence of the stream; again support for the idea that the predation that causes extreme disparity in Masset Inlet occurs locally (Barber 1979a). The Tlell River rises in a similar drainage area adjacent to the Yakoun and also has a run in the off-year (Marshall et al. 1978).

7) Of pink salmon fluctuations in eastern Alaska, Royce (1962, p. 23) said, "In 1960 the lowest pack of the century occurred." Production was also down in Prince William Sound in 1960. "Production in 1932 in south-eastern Alaska was down, but only as a response to "gear restrictions" apparently (Royce 1962, p. 24). The run of pinks to the Skeena River was down in 1932; Neave (1966, p. 77) termed the decline in 1932 from 1930 a "crash" and noted that the dominant year class changed. On the other hand, "The salmon runs to all districts, with the exception of Queen Charlotte Islands, were of fair proportions" (Howe 1933). It is likely then that decreased runs in 1932 occurred to areas adjacent to the northern Queen Charlotte Islands, but only the evidence concerning the declines to the islands is unequivocal.

8) That the migration route of Pacific salmon returning to rivers in British Columbia may be influenced by the extent that an unusual water mass intrudes northward along the coast is not new, and was discussed often at the Pacific Oceanographic Group (frontispiece) in the 50s; the basic consideration was that, "The spawning migration of sockeye salmon...in the ocean was shifted northward..." (Tully et al. 1960, p. 61; see also Anon. 1960, p. 3). The migration route off the coast of British Columbia is taken as that of Royce et al. (1968; see also Larkin 1977) wherein most returning adults move southeastward close to the coast as they finally leave the ocean while the young are moving to the northwest into the ocean (Neave 1964).

Neave (1966) remarked, "... pink salmon reach the Fraser and streams on the east and west sides of Georgia Strait both via Juan de Fuca Strait and Queen Charlotte Sound and, similarly, the Skeena and streams in the central coastal area are supplied via both Queen Charlotte Sound and Dixon Entrance. The proportion of the runs utilizing a given approach, however, may vary considerably in different years." Evidence in literature for alterations of route of the young or adult include the following:

(i) In 1971 adult fish bound for the Fraser River came into the coast further north than usual in that a large proportion made a landfall off the west coast of Vancouver Island rather than the coast of Washington (Anon. 1972, p. 27).

(ii) Gilhousen (1962, p. 107, 110) suggested that "warm water along shore" could move young pinks offshore where the predation was more intense, thus years of unusually warm weather would lead to an unusual level of predation. He also noted that a part of the run to the Fraser passes south through Johnstone Strait.

(iii) Manzer and Shepard (1962) suggested that "changes in the marine environment" could cause differences from year-to-year in pink salmon migrations and provided data for 1957 and 1958; years in which such a difference seems to have occurred.

(iv) Favorite (1961) suggested that the "seaward extent of dilute water" may have influenced the route taken in 1958 by returning sockeye, whereas Favorite and McLain (1973, p. 143) noted "that unusually warm conditions were considered to be one factor."

(v) The proportion of Fraser sockeye returning through Johnstone Strait in 1978 was unusually large and "was not predicted by any of the near-coastal environmental factors and models that had been used in recent years with some success, and obviously further study is necessary" (Anon. 1979, p. 34).

So the events of the late 1950s were of considerable interest (Sette and Isaccs 1960) and it would seem unlikely that a similar intrusion in the 1930s would have passed without being noted. The ocean off the west coast was being studied, particularly in relation to the halibut fishery, and fishermen generally were aware that the occurrence of exotic fish were often the result of such intrusions. In the Canadian Fisherman for 1931 there are a number of relevent references and in the December issue Dr. J.L. Hart is reported (p. 25) to have conceded "that there does appear to be some evidence for a northern migration of southern forms." Thomson (1972) provided a mechanism "for the well-known annual variations in the northward penetration... off the British Columbia coast," which generally seem to be reflected in surface and subsurface temperatures (Fofonoff and Tabata 1966) and zooplankton (Sund 1958; LeBrasseur 1959). Dodimead and Pickard (1967) discussed the distribution of the intrusion in a number of years about 1958 and showed (their fig. 5) that in the summer of 1959 the temperature at the top of the halocline was unusually warm along the coast to the latitude of Dixon Entrance.

Annual mean sea-surface temperature in 1931 was colder than normal (Favorite and Ingraham 1976), while departures for each quarter also indicate

colder surface temperatures in the second half of 1931 (Patterson 1934, his Table 2). Monthly mean sea-surface temperatures "near" 50°N, 145°W appeared to be near normal during 1931 (Collins et al. 1975). Neither subsurface temperature data, i.e. at the top of the halocline, nor plankton data for the region have been located, but in the report concerning the anomalous intrusion of the late 1950s (Sette and Isaccs 1960) there are a number of references to conditions in 1931 (p. 41, 81, 87) which carry the implication that the year was anomalous, at least off the west coast of the United States.

9) Some of the early data on size was determined by the number of fish delivered and the number of cases packed. RBA indicated that economics could bear on this through changes from year-to-year in the extent of wastage permitted; I recall several occasions in the early 1930s when a scowload (60-80 tons) would be sent to the reduction plant or dumped (see also RBA, p. 18).

The run to the Fraser River in 1961 was very small in number and was, according to the Salmon Commission, due to a combination of overfishing in 1959 and high mortality of eggs of the subsequent escapement (Anon. 1962, p. 21). The Commission also believe that an inverse relationship between abundance and weight can occur in a run and use fish size in the early run to forecast abundance that season (Anon. 1972, p. 27; 1975, p. 17; RBA, p. 5). Larkin (1977, p. 175) believed the evidence supporting the relation to be conflicting.

10) Here I assume the pink fry are not cannibalistic and while it is not critical to the main thesis there is no evidence in support of the assumption. The observations of Okada and Taniguchi (1971) suggest that some of the larger pink fry could consume some of the smaller fry.

11) Perhaps the schooling of fry stimulates attacks by the adult in a behaviour not influenced by the degree of hunger (Fox 1975, p. 90).

12) A recent tabulation of the Salmon Commission (Anon. 1978, p. 20) indicates minor changes to the pink salmon returns shown here in Table 2 and Dr. W.E. Ricker has provided mean weights by statistical area for several years, including 1976 and 1978. The Salmon Commission also has provided a preliminary value of their determination of adult returns to the Fraser in 1979 as 20.7 million pink and sockeye, which permitted a forecast of mean whole weight of seine-caught fish by statistical area in 1980 as:

Area	1	2E	3	4	5	6	7	8	12	13
Weight (lb)	2.6	2.6	2.4	2.5	2.5	2.5	2.5	2.5	2.5	2.8

leave alone